HIGH LEVEL CONTROL SYSTEMS

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PT 98/14350/E (Revision of PT 94/4191/E)

Summary

For more than 30 years, the cement industry has been exploring computer-based techniques to control and optimize the operation of cement kilns. The major reasons behind these endeavours are clinker uniformity, savings in energy consumption, increase in production, savings in refractory consumption and NOx reduction. Basically, cement kilns are difficult to control because of their non-linear, multivariable, behaviour and the poor quality of the available process signals. After several trials to describe the burning process with mathematical models a new approach in cement kiln control was investigated in 1980. Operator control strategies were studied, and a detailed record of the operator's behaviour was made while controlling the kiln. These "fuzzy" rules can imitate multivariable control actions and can combine information from variables to identify the kiln conditions. Within the "Holderbank" group, specific requirements of such a High Level Control (HLC) system was defined to compare the several suppliers. The system from ABB LINKman is the most powerful real-time expert system with very advanced features and a high user-friendliness. A standard implementation plan was made to reach a successful application of the system. The preparatory work in the plant must be carried out according to the recommendations made during the pre-project study. The identified process problems have to be solved. To achieve the "Best Operator Performance" the detailed and rigorous monitoring of the HLC performance is obviously essential at this stage. The optimization of the process with respect to product quality and related process factors, on a long-term basis, is the key to the ultimate level of savings arising from the HLC application. It is this optimization that can give the plant additional benefits over and above those arising from the average operator to „Best Operator Performance". The experience shows that substantial benefits like higher kiln output, lower heat consumption, longer refractory life, lower NOx emissions and lower standard deviation of the key variables can be expected from HLC systems, if they are properly implemented and used. The experience shows that the payback of 1 to 2 years is realistic, when considering only the investment costs in the HLC system.

1. INTRODUCTION

For more than 30 years, the cement industry has been exploring computer-based techniques to control and optimize the operation of cement kilns. The major reasons behind these endavors are clinker uniformity, savings in energy consumption, increase in production, savings in refractory consumption, NOx reduction (Fig. 1 + 2, Annexes 1 + 2). The still high energy consumption of the cement manufacturing process, the stringent requirements on cement quality and the environmental aspects which are leading the governments to apply severe legislation regarding the emissions.

The classical process automation approach, consisting in defining a mathematical model of the process, led to only a very few successful kiln control applications. The improvement in the performance of hardware equipment, combined with the advent of artificial intelligence, is leading to a major step toward kiln control and optimization.

2. EVOLUTION OF HLC SYSTEMS

Basically cement kilns are difficult to control because of their non-linear, multivariable, behaviour and the poor quality of the available process signals. The control is then usually limited to a few secondary measurement loops, whereas the control of the primary parameters and the operating conditions are the responsibility of the kiln operators.

The first applied techniques were based on empirical or mathematical models. Although successful in simulating the kiln operation, these techniques were generally based on too many assumptions and used very complex theoretical models. For this reason they were not applicable and could not be extended to a broad selection of kilns. Other approaches such as the "hill climbing" techniques (Young et al, 1971) or statistical identification combined with optimal controller design by the state space method (Otomo et al, 1972) was also used but did not achieve any significant success.

Since the mid-seventies, a new approach based on the analysis of the human decision making in cement kiln control has been investigated (Umbers and King, 1980). Operator control strategies were studied, and a detailed record of the operator's behaviour was made while controlling the kiln. Basically this approach rests upon the concept of fuzzy logic introduced by Prof. L. Zadeh in 1965. The basic operator control rules were already prescribed by Peray and Waddell (1972). These "fuzzy" rules can imitate multivariable control actions and can combine information from variables, they work by identifying the kiln conditions and prescribing suitable corrective actions.

FL Smidth supplied the first commercially available kiln control system based on fuzzy logic in 1980. The concept of High Level Control was introduced at that time and is used to refer to systems, which provide not only supervisory control but also optimising control. Since then, many systems have been developed and are marketed. Some are using the concept of fuzzy logic and are called rule-based systems or are based on expert system shells. Others are more conventional and apply PID control or adaptive-predictive controllers. The penetration of HLC in the cement industry has been very intensive over the last decade, about 300 applications have been reported in kiln control applications.

3. SPECIFIC REQUIREMENTS OF A HLC SYSTEM

The following basic requirements were specified:

1) The provision of a high degree of user-friendliness; this aspect is extremely important, since kiln control strategy needs to be adapted when process conditions change. The maintenance of the application control strategy must be easy for the plant engineers to carry out.
2) The concept of "autopilot" as used in the previous version of the supplier's HLC system must be included to make it possible for the operator to switch the system on-line or off-line at any time without disturbing the process.
3) The use of a toolkit based on the G2 expert system shell which provides advanced features such as real-time facility, graphical interface and object-oriented programming; the toolkit, which is a software layer between G2 and the HLC applications, is the support for developing and implementing control strategies without programming skills.
4) The possibility for having multiple applications on the same system, typically one kiln, one cooler, mills and the kiln simulator.
5) The provision of a system incorporating tools and facilities allowing for consistent process optimization.
6) Very helpful for the introduction is the inclusion of a standard interface between the HLC system and the tailor-made kiln simulator in order to provide a training platform for the operators; this platform would allow for the simulation of kiln upsets and disturbances. The plant engineer would thus be able to develop and test new strategies before real implementation in the actual plant application. Figure 3 (Annex 3) shows a typical configuration.
7) The standardisation of the control strategies, in order to shorten commissioning time and make exchange of experience easier between different users. It is important to have a standardised way of both configuring and maintaining the control strategies.

Within the "HOLDERBANK" Group **LINKman** from ABB LINKman Systems Ltd, London, is applied. LINKman Graphic, the new version of this HLC system, is based on G2, a very powerful real-time expert system shell from Gensym Corp. LINKman Graphic is particularly user-friendly and offers very advanced features [4].

4. PROCESS OPTIMIZATION WITH HLC

As mentioned above, process optimization is the major target to be achieved. There are typically three phases associated with our concept of successful application. See also [3]. These phases are outlined below.

Phase 1: Plant Preparation

The preparatory work in the plant must be carried out according to the recommendations made during the pre-project study.

Phase 2: Achievement of „Best Operator Performance"

Very often bottlenecks are detected, process problems are identified and experience is gained in the period immediately following HLC implementation. Detailed and rigorous monitoring of the HLC performance is obviously essential at this stage. The identified problems then have to be addressed during the secondary commissioning. Attempts must be made to achieve the highest possible run time of the HLC system, typically 90 % or more, using an adequate and consistent control strategy. At this stage, the HLC is expected to operate with the same performance as the best operator with respect to production output, product quality, heat consumption, etc. The associated benefits depend on the size of the plant and the performance previously achieved in manual operation. This phase, based on the best operator know-how, can be considered as the foundation of the whole HLC project.

Phase 3: Process Optimization

The optimization of the process with respect to product quality and related process factors, on a long-term basis, is the key to the ultimate level of savings arising from the HLC application. It is this optimization that can give the plant additional benefits over and above those arising from the average operator to „Best Operator Performance". Process optimization mainly involves the plant technical staff. It requires an evaluation of the process performance, an estimation of the potential savings, which can be achieved, and an assessment of the control strategy performance. Since plant conditions change in respect to raw material quality, availability of alternative fuels, product quality requirements, etc., process optimization must be considered as a permanent task.

5. PRINCIPLES OF OPERATION

Basically, in the case of a conventional preheater kiln, HLC manages the control of the following parameters:

- the kiln feed rate
- the kiln speed
- the IDF speed (or damper position)
- the fuel to the kiln burner

In case of a precalciner installation, the precalciner fuel and the position of the tertiary air damper (AS system) have also to be controlled automatically.

The HLC system needs to access the process relevant data, such as preheater temperatures and pressures, the gas composition, the kiln amperage, the burning zone temperature, etc.

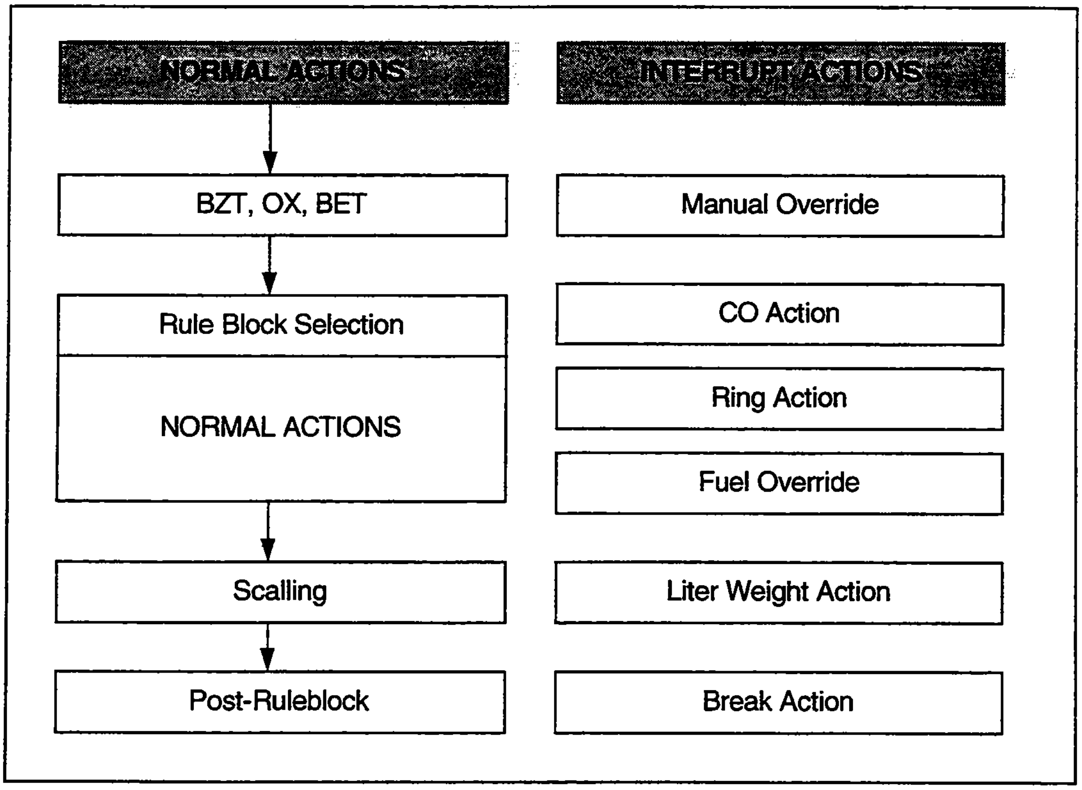
The principles of kiln control operation depend on the HLC system used. The principles used in LINKman are hereafter presented.

LINKman

LINKman works in two basic modes:

"Normal Actions" and "Interrupt Actions".

The approach used in LINKman is sequential. In a first phase, a specific logic checks whether the kiln is in normal operation or in upset situation.



Normal Actions

If the kiln is in normal condition, then the parameters BZT, OX and BET are calculated.

- BZT (Burning Zone Temperature) represents the clinker burning degree, calculated out of NOx, Kiln Amps, and zone temperature.
- OX, the draught index, based on the gas composition at kiln inlet.
- BET (Bet End Temperature): the degree of preparation of the material when entering the kiln.

LINKman selects then one of 4 ruleblocks to determine the required setpoint changes, depending on:

- the deviation between the actual feed rate and the desired target,
- the spare draught capacity,
- The process conditions.

Rule Block	Actions on
General	Feed, Fuel, Fan
Top-feed	Fuel, Fan
Top-damp	Feed, Fuel
Stable	Fuel

The changes calculated using the ruleblocks are scaled to physical changes. However these changes are merely based on the present kiln conditions. Specific actions are then carried out, if required, to take into account the previous actions and the process dynamics, they are included in the "Post-Rule Block Processing" module.

Interrupt Actions

If a kiln-upset condition is detected, a dedicated control action is applied. As these actions have a higher priority than the normal actions, they are called interrupt actions.

Examples:

Break-Action	if the kiln is in unstable conditions for a longer period
Ring-Action	if a ring fall is detected
Hot-Action	if the kiln gets very hot
CO-Action	if a high amount of CO is detected

6. BENEFITS AND KEYS OF SUCCESS

The experience shows that substantial benefits can be expected from HLC systems if they are properly implemented and used. The following table shows typical ranges of quantifiable benefits:

Item	Typical Range
Kiln output	+ [0 - 5 %]
Heat Consumption	- [0 - 5 %]
Refractory Life	+ [0 - 30 %]
Long-term clinker strength	+ [0 - 5 %]
Electrical energy for clinker grinding	- [0 - 10 %]
NOx emissions	- [0 - 30 %]
Number of kiln stops	- [0 - 30 %]
Standard deviation of key variables	- [0 - 50 %]

In addition, the following qualitative benefits have to be mentioned:

- The working conditions of the operators are greatly enhanced. As the computer handles the routine tasks, the operator can concentrate on more important matters.
- Process analysis and optimization are made more easily since opportunities for testing new control strategies and new ideas are available, assuming that the HLC is user-friendly enough.
- The use of HLC imposes to keep the instrumentation in a good operating state.

The keys of success with HLC systems are:

- An adequate and reliable instrumentation (sensors, actuators, PID controllers, etc.)
- A stable and uniform raw mix chemistry
- An optimized combustion
- A highly motivated personnel
- A follow-up of the performance of the system

7. HOW TO JUSTIFY AN INVESTMENT IN HLC

In order to justify an investment in HLC, it is important to estimate the potential cumulative savings over the lifetime of the system. Figure 4 (Annex 4) gives an illustration of these savings over a period of ten years.

In this figure, curves 1, 1a and 1b indicate the cumulative savings with HLC when achieving „Best Operator Performance". If the HLC has a robust strategy and is permanently adapted to the evolution of the burning process, then the cumulative savings will increase consistently according to curve 1.

However, if the system is not properly maintained or not adjusted to changing process conditions, sooner or later it will stop functioning and the savings will obviously stop. These situations can take place very shortly after installation (curve 1a) or later on (curve 1b).

Curve 2 illustrates the cumulative savings, which can be realized in cases where the HLC is used as a tool for permanent process optimization. These extra savings are on top of the savings indicated on curve 1. The benefits resulting from this optimization can be achieved after reaching an HLC run time of more than 90 %. The savings through optimization can increase even more if the original HLC application is extended to other plant areas such as raw milling, stack gas flow control or integration of an efficient raw mix control strategy.

To summarize, simply by achieving „Best Operator Performance", the payback is generally less than two years (considering only the investment in HLC). Furthermore, if the HLC is used efficiently as a permanent optimization tool, then the cumulative savings will increase even more.

The experience shows that a payback of 1 to 2 years is realistic, when considering only the investment costs in the HLC system.

8. CONCLUSION

Over the last decade, HLC systems have penetrated the cement industry. About 300 applications have been reported which represents roughly 15 % of the cement manufacturing installations.

There is no doubt that the proper implementation and use of a HLC system, although requiring relatively low investment costs, provide significant enhancements in terms of productivity.

However it is of the utmost importance to select the adequate system, that means a system which has proven to be efficient and performant in the long term.

It must be remembered that the success of any HLC system depends upon:

- the quality of the instrumentation
- the raw meal preparation
- the quality of the combustion system
- the motivation of the works' personnel and the acceptance of the system by the operators

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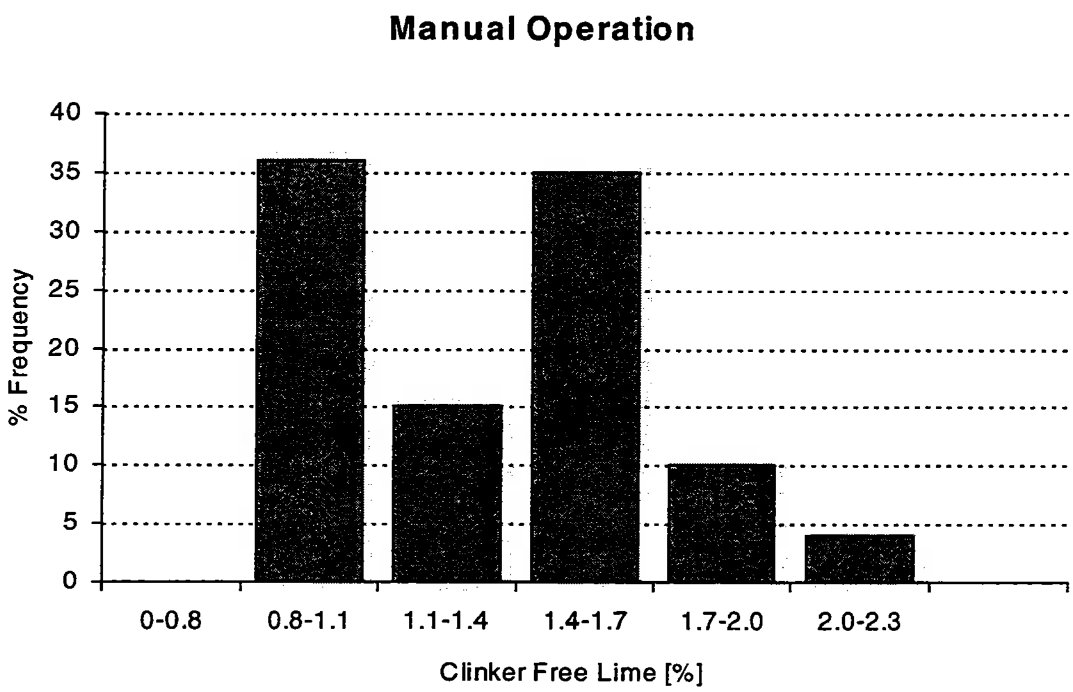
10. ANNEX

Figure 1: Example of Improved Clinker Uniformity



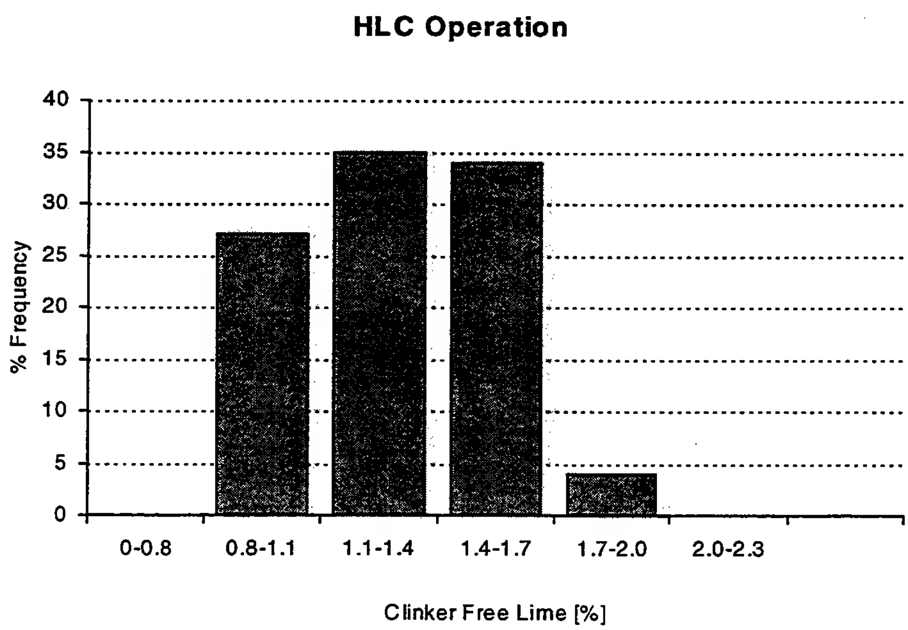


Figure 2: Example of Improved Heat Consumption

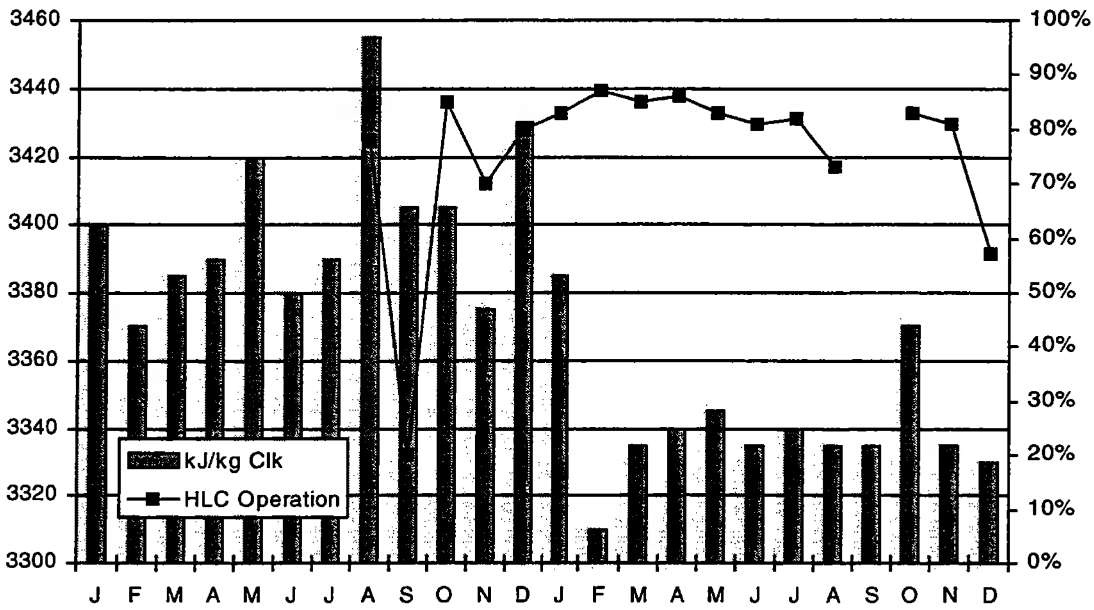


Figure 3: Operator Training

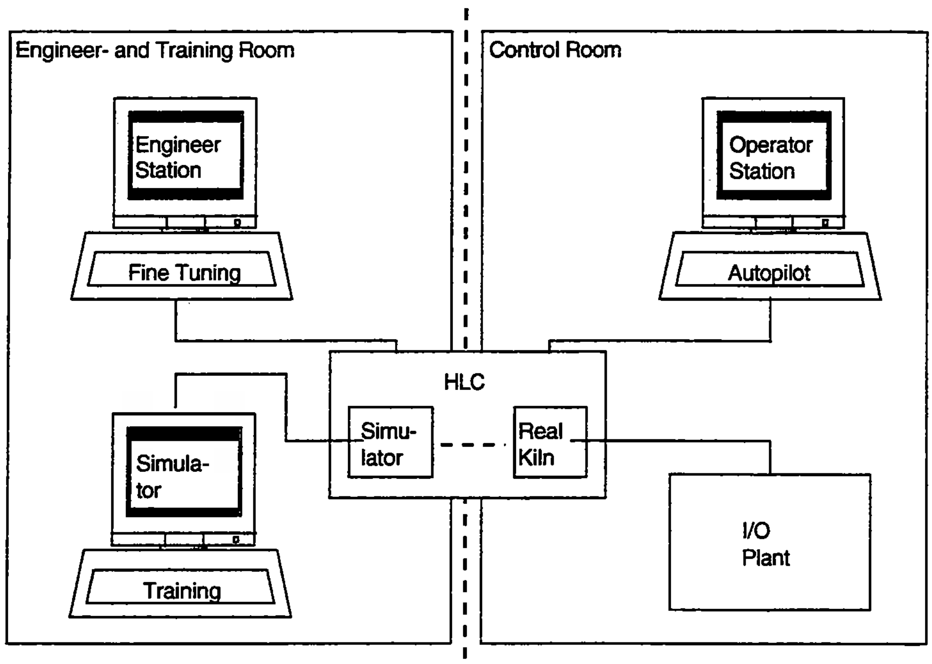


Figure 4: Lifetime Benefits of Process Optimization with HLC